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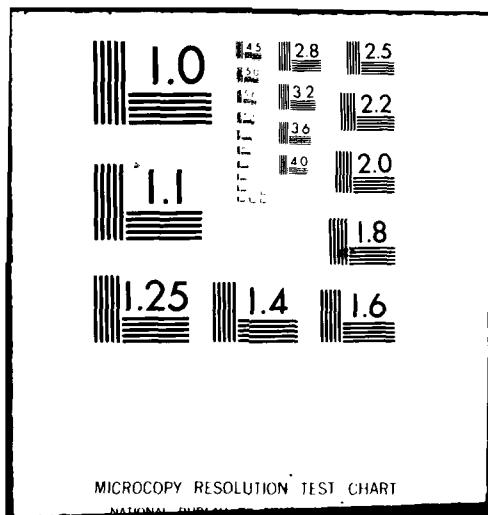
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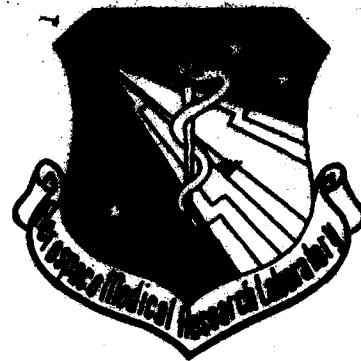
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## THE EFFECTS OF COLOR AND CONTRAST ON TARGET RECOGNITION PERFORMANCE USING MONOCHROMATIC TELEVISION DISPLAYS

ALAN R. PINKUS

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MAY 1982

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

**FOR THE COMMANDER**



CHARLES BATES, JR.  
Chief  
Human Engineering Division  
Air Force Aerospace Medical Research Laboratory

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20. ABSTRACT (Cont'd)

Each of the twelve subjects viewed five different types of targets at four diagonal orientations, each under six television display conditions. For each trial, the target (located in the center of the television) started small and unrecognizable, then slowly enlarged until it became recognizable. At the moment of recognition, the subject pressed a projector stop button and identified the target. The experimenter then measured the target's size. Results showed that color did not significantly affect subjects' target recognition performance ( $p = 0.25$ ). Contrast was highly significant ( $p < 0.001$ ), thereby replicating several previous studies. There was no color by contrast interaction ( $p = 0.70$ ), but targets and color by targets were significant ( $p < 0.0001$  and  $p < 0.02$ , respectively).

## PREFACE

This work was accomplished at the Crew Systems Effectiveness Branch, Human Engineering Division, Air Force Aerospace Medical Research Laboratory under Project 7184, Man-Machine Integration Technology, Work Unit 7184-11-44, Image Display Mensuration/Enhancement. Research was monitored by Dr. Harry L. Task.

The author gratefully acknowledges the tremendous support of Dr. Task. He was an invaluable source of guidance through the study and text preparation. Thanks also to committee chairmen Dr. Frank DaPolito and Dr. Samuel Bower for their time, encouragement, and constructive criticism. Thanks to Rick Hubbert for his assistance in equipment calibration during the course of the study.



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## INTRODUCTION

Since the advent of monochromatic television (TV) display devices, the number of phosphors for cathode-ray tubes has increased to over 50 types (Westinghouse, 1972). Any given phosphor is chosen for its electrical, temporal, and spectral characteristics. Spectral characteristics include peak wavelength, fluorescent color, phosphorescent color, and the spectral energy distribution (SED) curve. The SED curve, which is used to calculate the CIE (Commission Internationale de l'Eclairage: an international light specification organization) color coordinates of a phosphor, is the relative energy output of a phosphor plotted as a function of wavelength.

Various TV display applications require the use of different phosphor colors. Television displays used for aircraft instrumentation purposes often have a green, P-1 phosphor because of the high luminance levels that can be obtained. Night TV display applications typically specify a red phosphor such as P-22R so the operator can maintain his partially dark-adapted state. White, P-4 phosphor is used in general display applications. Subjective reports from the field have indicated it is less fatiguing and more pleasing to view the black and white TV.

The question arises as to whether or not any of the three different display colors previously mentioned adversely affect operator performance. For the purposes of this study, operator performance is operationally measured using the visual angle (in degrees) subtended by a target on the TV display at recognition. Correct recognition of a target at a small visual angle corresponds to a target that is relatively far away. Conversely, a large visual angle means the target is closer and the time required by the observer to recognize the target is longer. This study examines the effect of different TV colors on observer performance in terms of the angle subtended by the target at recognition.

Previous studies (Task, 1979; Bruns, Bittner, and Stevenson, 1972; Erickson and Hemingway, 1970) have shown that target contrast can significantly affect target recognition performance. Therefore, contrast (two levels) was included as a variable to determine if there was an interaction effect with TV display color.

In the past, the selection of phosphor color for a tactical TV display system has been based on the environment in which it was used without consideration for its possible main effect, or its interaction effects with display contrast and targets, on an observer's target recognition performance. This study provides additional information about these various effects.

## METHODS

### Subjects

Five females and seven males ranging in age from 18 to 35 years of age participated in this study. Visual acuity for all of the subjects was tested and determined to be 20/20 or better (corrected or uncorrected). Subjects were also given a test for color deficiency using the Dvorine 1955 pseudo-isochromatic plates test. This test was performed under a standard illuminant "C" white light source. All subjects had no major color deficiencies.

### Stimulus Materials

A threshold type of stimulus presentation was used for this study. Military ground vehicle targets served as stimuli. The targets were: tank (T), mobile gun (MG), covered truck (CT), half-track (HT), and uncovered truck (UCT) (see Figure 1). Black and white 8 x 10 inch photographs were made of each target at four different diagonal orientations, on a rectangular mottled background tile. The mottled background tile helped to obscure any prominent silhouette information. Five targets, at four orientations each, yielded a set

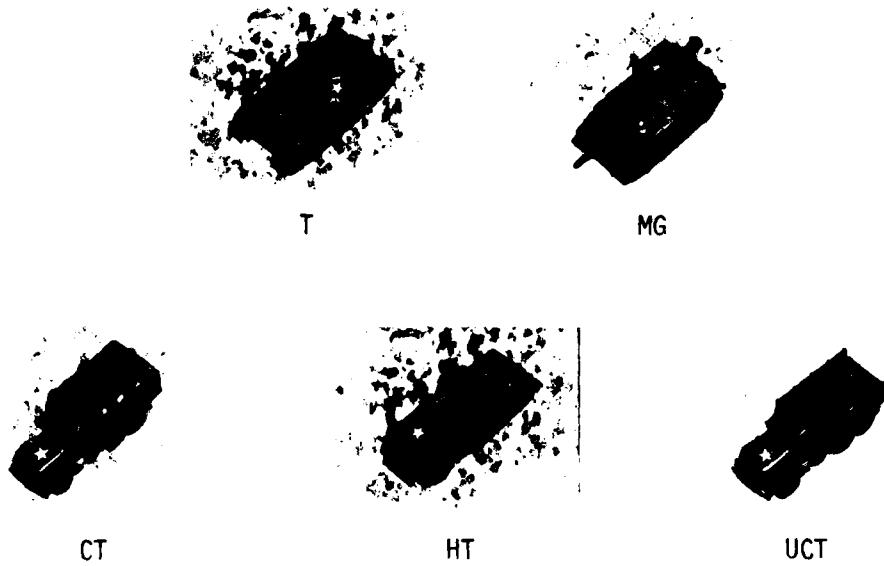


Figure 1. Photographs of Targets Used as Stimuli

of 20 target situations. To create the threshold film imagery, each 8 x 10 inch photograph was mounted on an upright, gray background board. While filming the mounted photograph, the motorized zoom lens of a 16mm motion picture camera was slowly adjusted from minimum to maximum magnification (1:6.5 X; approximately 17 seconds duration). This procedure was repeated for all of the targets. When a subject viewed the film through the television system, the target first appeared in the center of the screen, very small and unidentifiable. As the target size increased, it eventually became identifiable. No visual search was required of the subject. The order of the targets was randomized by reslicing the film. Luminance and contrast values for each target in all display contrast conditions appear in Table 1.

TABLE 1. MAXIMUM AND MINIMUM TARGET LUMINANCES (L)  
WITH CALCULATED CONTRAST (C) VALUES

Target	Display Contrast Ratio					
	40:1			40:20		
	L max.	L min.	C	L max.	L min.	C
Tank	3.60	0.71	0.67	4.04	2.67	0.20
Mobile gun	3.29	0.48	0.75	4.03	2.60	0.22
Covered truck	3.90	0.34	0.84	4.45	2.48	0.28
Half truck	3.40	0.32	0.83	3.99	2.35	0.26
Uncovered truck	4.20	0.69	0.72	4.39	2.56	0.26

Note: L max. and L min. are in footlamberts. C =  $\frac{L \text{ max.} - L \text{ min.}}{L \text{ max.} + L \text{ min.}}$ .

#### Equipment

Figure 2 shows a functional block diagram of the experimental apparatus (see Appendix A for the equipment list). The 16mm threshold target imagery was projected directly onto the surface of a 1-inch vidicon TV camera tube. The output of the camera was connected to an oscilloscope and two 14-inch diagonal, black and white TV displays. An oscilloscope, in conjunction with a photographic camera, was used to monitor and document the video output signals from the TV camera. The experimenter used one TV to monitor and measure the stimuli during the experiment. A video digitizer was used to measure the size of the targets. The video output from the camera also passed through a blanking circuit and then to the subject's TV. The TV raster size was 7.5 x 10 inches. The film projector was equipped with a remote

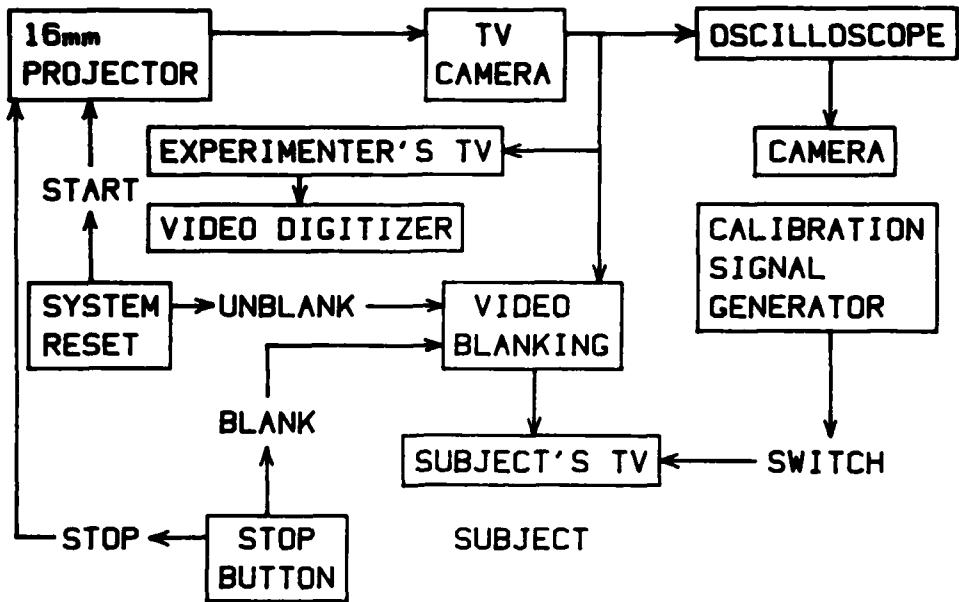


Figure 2. Functional Block Diagram of the Video System Used in the Study

stop button that the subject pressed when he could name the target. When the stop button was pressed, the blanking circuit switched the subject's TV to a uniform flat field luminance that was preset by the experimenter to a nominal 25 footlamberts. Blanking the monitor disallowed the subject extra time to study the targets. After the size of the image was recorded, system reset buttons were used to restart the projector. When the next target appeared on the film, the subject's TV was unblanked. A description of a similar video system is in Task and Verona, 1976, page 29.

### Television Display Color and Contrast Calibration

In order to simulate the green P-1 and red P-22R phosphors, colored and neutral density Wratten (WR) gelatin filters (Kodak, 1973) were used to vary the spectral and luminance characteristics of the white P-4 phosphor monitor that was viewed by the subject. Figure 3 shows all of the SEDs for the three phosphors and the two simulated conditions. Table 2 summarizes all of the filter combinations.

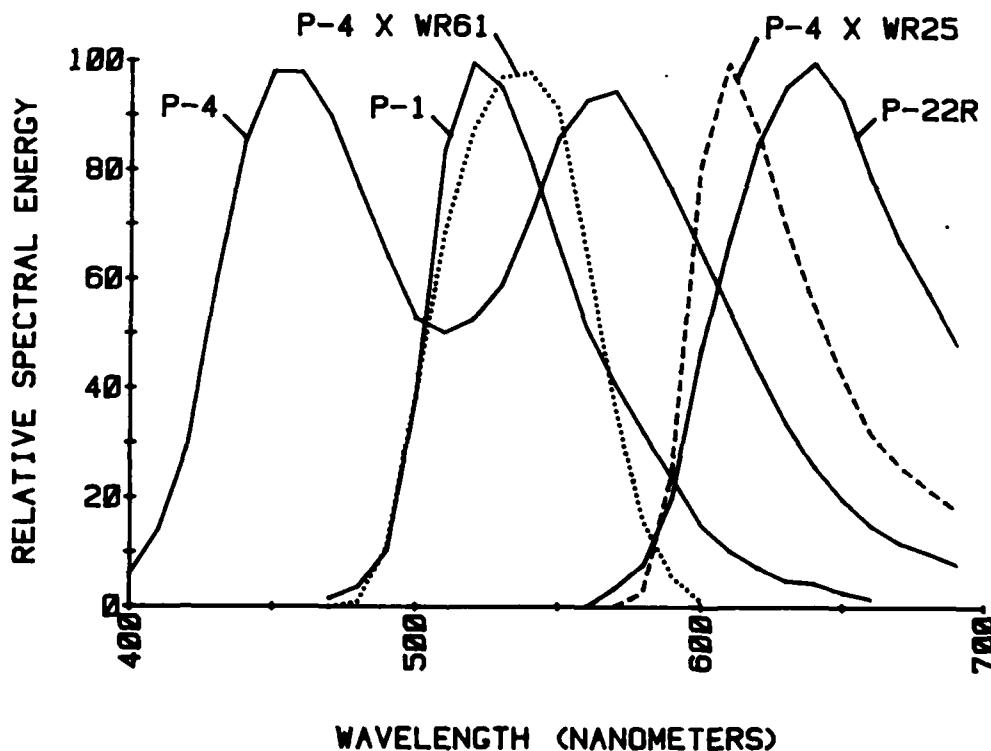


Figure 3. Spectral Energy Distribution Curves for P-4, P-1, and P-22R Phosphors. Dotted and Dashed Lines are Spectral Energy Distribution Curves for P-4 Times Wratten Filters (WR) 61 and 25, Respectively

TABLE 2. FILTER COMBINATIONS USED TO VARY THE SPECTRAL ENERGY DISTRIBUTION OF THE WHITE TV IN ORDER TO SIMULATE GREEN AND RED TV PHOSPHORS

Display Color	Peak TV Luminance (Source)	Wratten Filter Number	Neutral Density Filter	Final Transmittance to Subject	Simulated CIE (Phosphor CIE)	
					x	y
White, P-4	40 ftL	--	1.1	3.2 ftL	0.333 (0.333)	0.347 (0.347)
Green, P-1	40 ftL	61	0.3	3.2 ftL	0.251 (0.218)	0.693 (0.712)
Red, P-22R	40 ftL	25	--	3.2 ftL	0.674 (0.660)	0.326 (0.334)

The subject's TV (Tektronix 632) was designed to be a visual match to a D6500 degree Kelvin white light source. Curve P-4 in Figure 3 was the SED of the TV and its CIE coordinates (see Riggs, 1965, pages 17-19) were  $x = 0.333$  and  $y = 0.347$ . A 1.1 neutral density filter (8 percent transmittance) was used to attenuate the 40 footlambert source (peak output of subject's TV) to 3.2 footlamberts of white light. Note that in Table 2 all final transmittance values were fixed at 3.2 footlamberts because the WR25 filter alone had the greatest attenuation and was, therefore, the limiting factor in all other filter combinations.

The green phosphor was simulated by combining WR61 and 0.3 neutral density filters to attenuate the 40 footlambert source to 3.2 footlamberts. Figure 3 compares the P-1 SED to the P-4 times WR61 SED (dotted curve) which is the simulated green condition. CIE color

coordinates for P-1 were  $x = 0.218$  and  $y = 0.712$  while the simulation's coordinates were  $x = 0.251$  and  $y = 0.693$ .

The red phosphor was simulated by using a WR25, which attenuated the 40 footlambert source to 3.2 footlamberts. Figure 3 compares the P-22R SED to the P-4 times WR25 SED (dashed curve) which is the simulated red condition. CIE color coordinates for P-22R were  $x = 0.660$  and  $y = 0.334$  while the simulation's coordinates were  $x = 0.674$  and  $y = 0.326$ . See Figure 4 for a plot of all the coordinates in CIE space.

The filters were mounted onto goggles which allowed easy changing of experimental conditions and also allowed subjects who wore glasses to participate in the experiment.

Two TV display contrast ratio conditions (40:1, 40:20) were achieved by adjusting the brightness and contrast controls with reference to a square-wave video input signal that had a peak-to-peak voltage matched to the camera's output signal. As shown in Figure 2, the video output of the television camera was connected to the subject's monitor. This signal ranged from 0.5 to 1.2 volts peak-to-peak above the synchronization pulse. A 0.5 to 1.2 volts peak-to-peak square-wave (8 cycles per TV raster width) from a video signal generator was substituted for the camera signal. During this calibrate condition, the square-wave signal appeared on the subject's TV as 16 alternating black and white vertical bars. Bar number 5 from the left was arbitrarily designated as the peak luminance bar, and bar 11 was the low luminance bar. Using a telephotometer (Pritchard 1980A), the brightness and contrast controls were iteratively adjusted until the

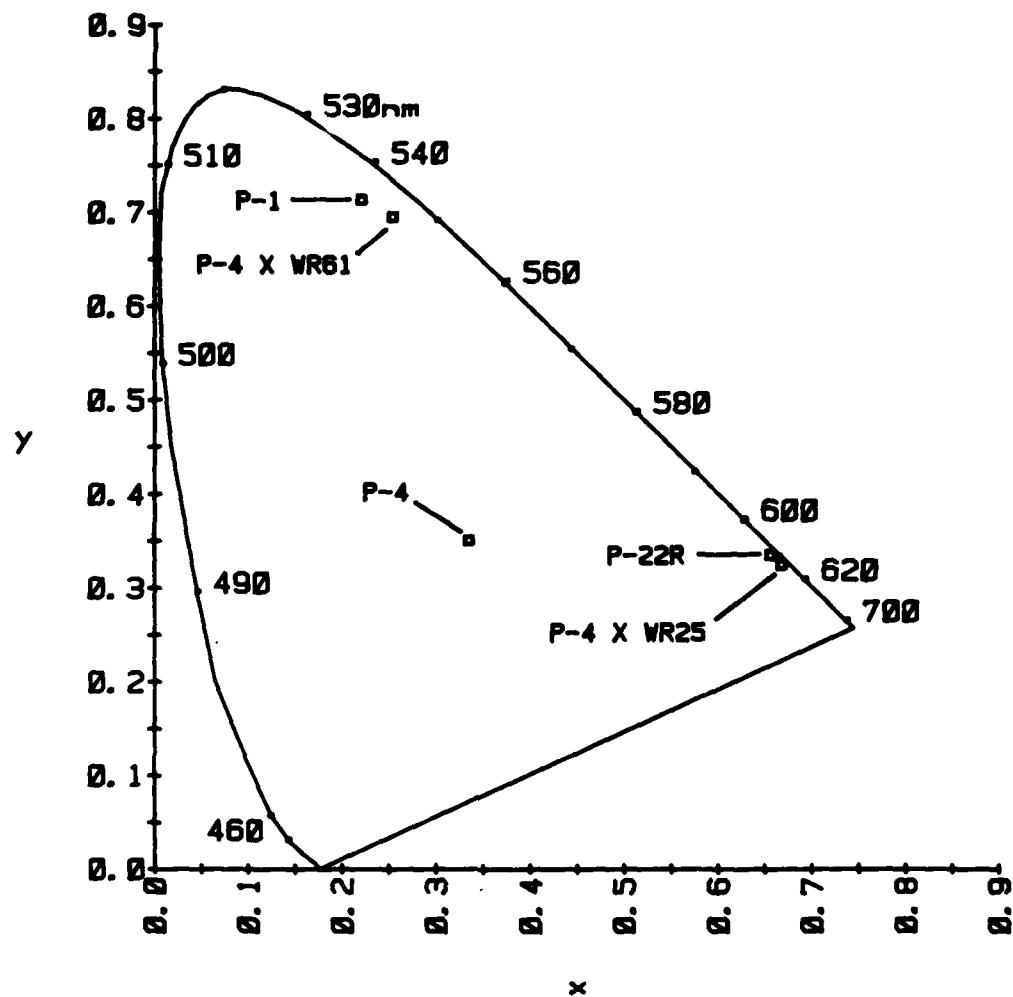


Figure 4. Commission Internationale de l'Eclairage Color Coordinates of P-4, P-1, P-22R, P-4 Times Wratten Filter (WR) 61, and P-4 Times WR25

peak and low bars were either 40 and 1 or 40 and 20 footlamberts, respectively, depending upon the contrast ratio condition.

Using a calibration signal that was matched to the camera's video signal assured that the brightest and darkest areas of the stimuli never exceeded the desired display contrast ratio. This procedure

also prevented the occurrence of black level clipping which is a loss of information from the darker areas of a picture. For a more complete description of the theory and procedure for TV contrast calibration, see Task and Verona, 1976, page 12.

Modulation transfer functions were measured for the 16mm movie film and the TV camera; sine wave responses (SWRs; see Task and Verona, 1976, page 8) were measured for the TV display at the two display contrast ratios (electronics included). The multiplied film and TV camera curves were then separately multiplied by the two TV SWRs in order to obtain the two system curves shown in Figure 5. These curves represent the maximum contrast possible on the display as a function of spatial frequency for each of the contrast conditions. Note that due to the multiplicative effect of the system's components, the modulation contrast values at 10 cycles/raster width (see Figure 5) were slightly lower than the label 40:1 (0.95 TV contrast) and 40:20 (0.33 TV contrast) values.

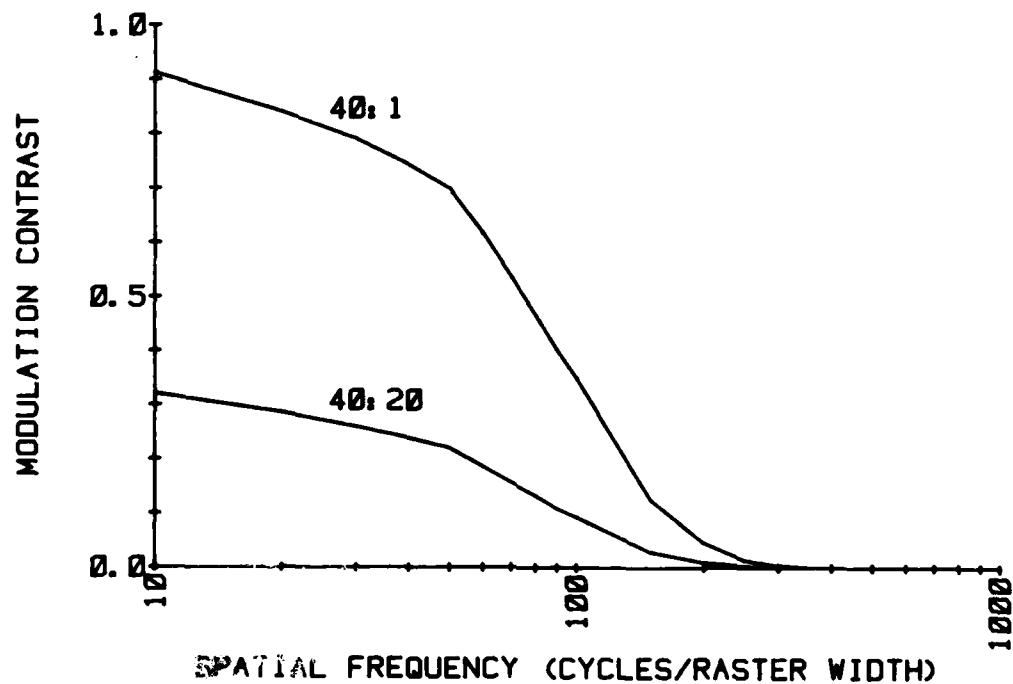


Figure 5. Film/Video System Sine Wave Response Curves for 40:1 and 40:20 TV Display Contrast Ratios

#### Procedure

The testing regime for one subject is outlined by this procedure. A subject listened to prerecorded instructions while also reading them:

The experiment, in which you are about to participate, is concerned with various types of television displays and how they might affect a subject's target recognition performance. You will see televised films of military targets, and you will press a button that stops the film projector when you can recognize a target. Now, open your briefing book. This book contains large, high detail photographs of targets. Later, you will be required to identify similar photographs by name. The targets are: a covered truck, an

uncovered truck, a half track, a mobile gun, and a tank. Please study and memorize these names and distinguishing characteristics. During the test, the targets will appear one at a time in a random order. Each target can occur in any one of four diagonal orientations. These photographs are examples of each target at only one of the four orientations. Remember that different orientations will cause a target to look a little different. When you are seated in front of the television and the experiment begins, the experimenter will say "next target." Some target at some orientation will then appear in the center of the television, but it will be very small and unidentifiable. The target will then begin to get larger and larger allowing you to eventually identify the target. You will now be given five minutes to study the five targets and then these instructions will continue. Remember to memorize their names and distinguishing characteristics so you don't confuse them with each other. (5 minute study period) Your time is now up. If you have any questions ask the experimenter after the tape is finished. Remember, your job is to press a stop button when you are virtually certain you can name the target. When you press the button, the film projector will stop and your television picture will temporarily blank out. After this occurs, say the name of the vehicle out loud so the experimenter can record your answer. I repeat, press the stop button when you are virtually certain you can name the target. Then tell the experimenter the target's name. If you have any questions at this point, please ask the experimenter.

The redundancy was used to better inform the subject of his task. He studied 8 x 10 inch photographic examples of all of the five targets for 5 minutes. He was instructed to memorize their names and distinguishing characteristics. After the study period, he was given instructions regarding the method of target presentation, the function of the stop button, criteria for recognition, and the manner of verbal response. After answering any questions, the experimenter showed the subject to the test station. Subject viewing distance was 28 inches from the TV. The subject was asked to relax but restrict movement of his head and body. In order to familiarize the subject with the

procedure, he was given 10 practice targets to recognize. The appropriately filtered goggles were then worn by the subject and 20 targets were identified during the 12-minute session. Between each of the six sessions, there was a 5-minute break except for a 20-minute break that occurred between the third and fourth sessions because the display contrast was recalibrated to a new experimental condition.

A session began by the experimenter saying "first target." The film was started, the display was unblanked, and a target started to become larger. The subject pressed the projector stop button when he was "virtually certain" he could identify the target (Martin, Task, Woodruff, and Pinkus, 1976, page 12). After the projector stopped, the display blanked to a flat field and the subject announced the target's name. The experimenter gave the subject feedback ("correct" or "incorrect" and the presented target's name), recorded the response, measured the size of the target with the video digitizer, and restarted the projector. At the appropriate moment, the experimenter said "next target" and the subject's display was unblanked. The whole procedure was then repeated.

## DATA ANALYSIS AND RESULTS

The size of the target at recognition was recorded by the video digitizer in arbitrary units. After converting these units to inches (100 units per inch), formula (1):

$$\text{Visual Angle} = \frac{2 \arctan}{\text{In Degrees}} \left( \frac{\text{Target Length in Inches}}{2 \text{ (Viewing Distance in Inches)}} \right) \quad (1)$$

was used to calculate the visual angle subtended by the target at recognition in degrees. These data were first analyzed, using a repeated measures within subjects analysis of variance (ANOVA; Kirk, 1968, pages 131-150). Mean target recognition performance scores for all experimental conditions are shown in Table 3, and the ANOVA summary data are shown in Table 4. Results of the ANOVA show the main effect of color to be nonsignificant, however, both display contrast and target type main effects were highly significant at less than the  $p = 0.001$  level. These general trends can be seen in the mean performance data of Table 3. Figure 6 is the data of Table 3 collapsed across targets and graphed to illustrate the lack of a color effect and the approximate 0.45 degree visual angle difference due to display contrast. Figures 7 through 12 show the subjects' target recognition performance data for all experimental combinations. The T, MG, and CT

targets as a group were recognized at relatively small sizes though their rank orders changed for different experimental conditions. The HT and UCT were consistently recognized at the second to largest and largest sizes, respectively. Again, the high contrast condition had better performance than the low contrast.

TABLE 3. SUBJECTS' MEAN TARGET RECOGNITION PERFORMANCE SCORES, WITH THE STANDARD DEVIATION (IN DEGREES) SHOWN BELOW EACH SCORE

Target	Display Phosphor Color		
	White	Green	Red
40:1 Contrast Ratio			
T	1.45 0.41	1.33 0.49	1.28 0.39
MG	1.43 0.31	1.26 0.37	1.32 0.35
CT	1.32 0.27	1.32 0.34	1.42 0.23
HT	1.78 0.42	1.65 0.52	1.70 0.41
UCT	1.92 0.39	1.86 0.37	1.84 0.45
40:20 Contrast Ratio			
T	1.84 0.48	1.79 0.39	1.88 0.48
MG	1.73 0.51	1.74 0.37	1.68 0.53
CT	1.85 0.33	1.84 0.35	2.03 0.50
HT	2.25 0.32	2.01 0.48	2.09 0.45

TABLE 3. SUBJECTS' MEAN TARGET RECOGNITION PERFORMANCE SCORES, WITH THE STANDARD DEVIATION (IN DEGREES) SHOWN BELOW EACH SCORE (continued)

Target	Display Phosphor Color		
	White	Green	Red
40:20 Contrast Ratio			
UCT	2.33 0.39	2.31 0.33	2.29 0.41

TABLE 4. ANALYSIS OF VARIANCE FOR THE EFFECTS OF COLOR, CONTRAST AND TARGETS

Source	Sum of Squares	df	F	P
Subjects	27.48			
Color (COL) Error	0.38 2.81	2 22	1.49	0.2471
Contrast (CON) Error	18.44 5.88	1 11	34.51	0.0002
Targets (T) Error	16.82 8.35	4 44	22.16	<0.0001
COL x CON Error	0.06 1.75	2 22	0.37	0.6971
COL x T Error	0.59 2.59	8 88	2.49	0.0172
CON x T Error	0.33 2.35	4 44	1.57	0.1993
COL x CON x T Error	0.26 3.69	8 88	0.77	0.6307

A significant color by target interaction effect ( $p < 0.02$ ) was also revealed by the ANOVA. Figure 13 shows the data collapsed across

the contrast conditions. Mean performance remained virtually constant for only the UCT target across color but the T, MG, CT, and HT targets changed considerably, thereby indicating where the color by target interaction occurred.

The color by contrast, contrast by target, and color by contrast by target interactions were all nonsignificant.

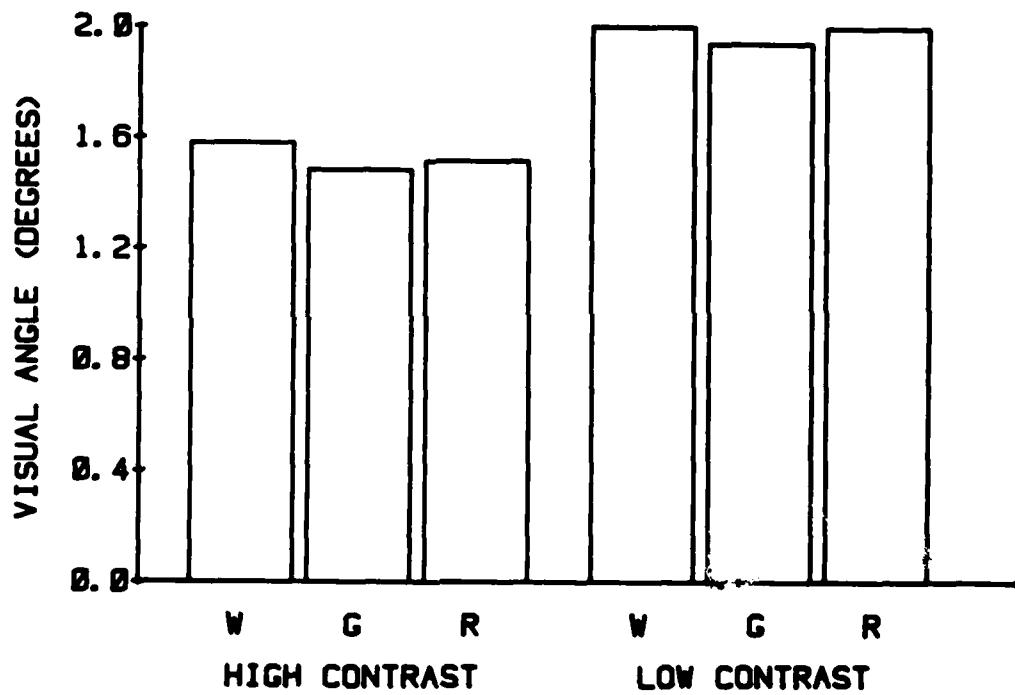


Figure 6. Subjects' Performance for White (W), Green (G), and Red (R) Displays at Both High and Low Contrasts Collapsed Across Targets

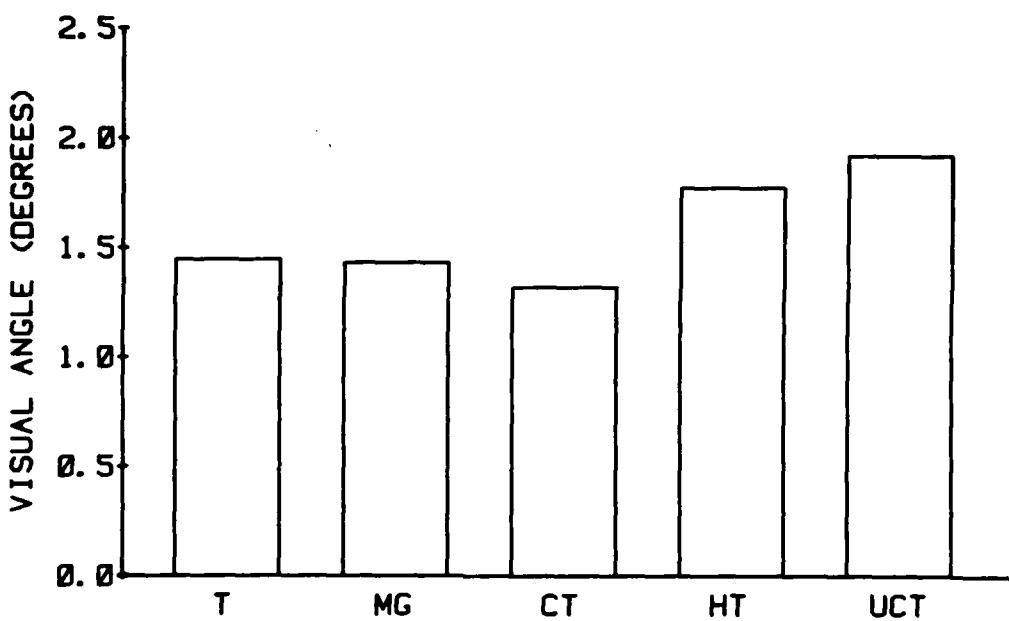


Figure 7. Subjects' Performance for Each Target While Viewing a White TV Display at a 40:1 Contrast Ratio

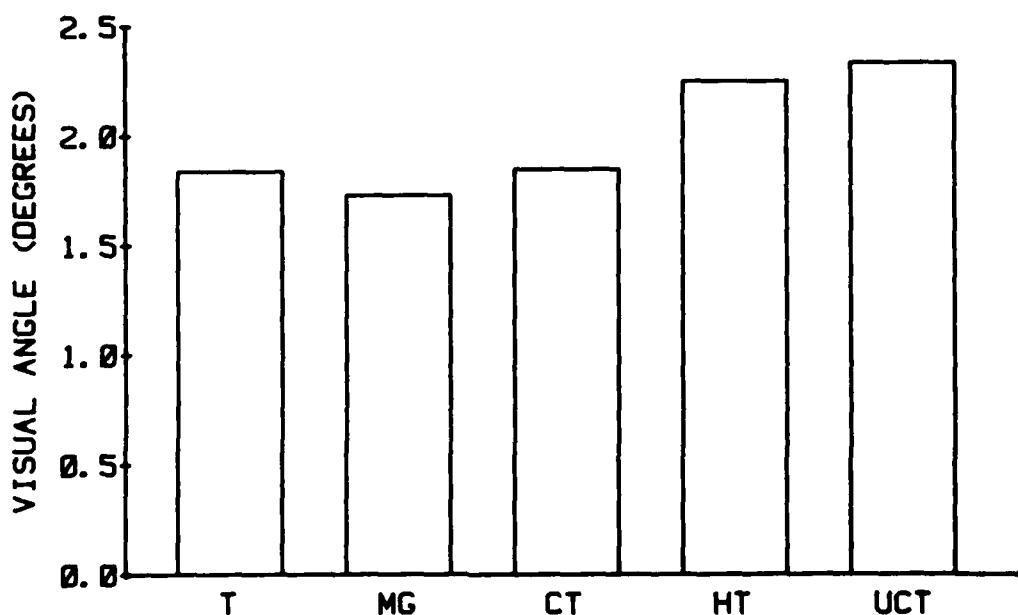


Figure 8. Subjects' Performance for Each Target While Viewing a White TV Display at a 40:20 Contrast Ratio

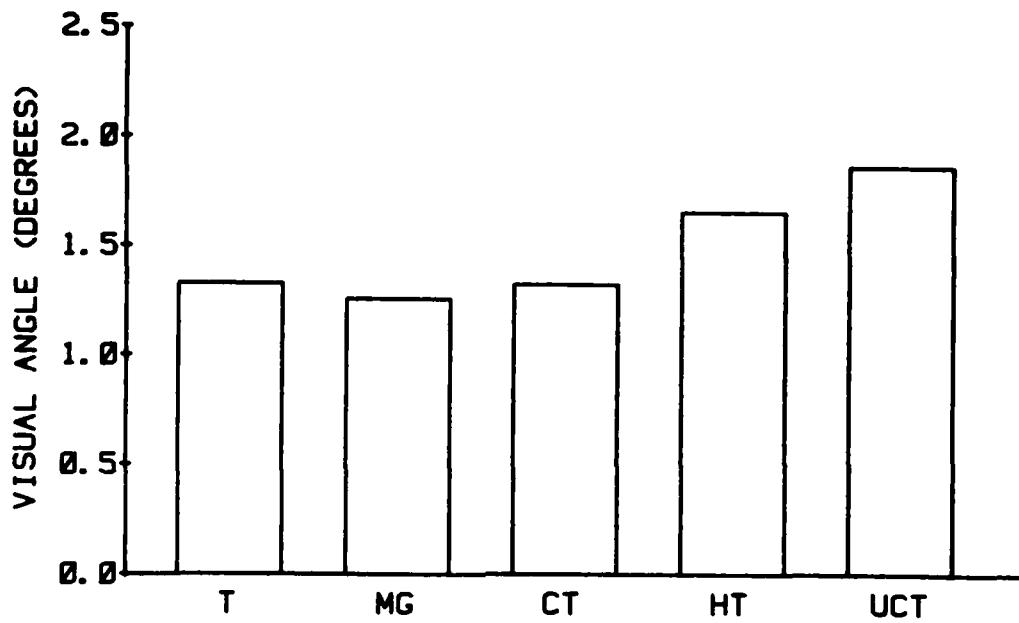


Figure 9. Subjects' Performance for Each Target While Viewing a Green TV Display at a 40:1 Contrast Ratio

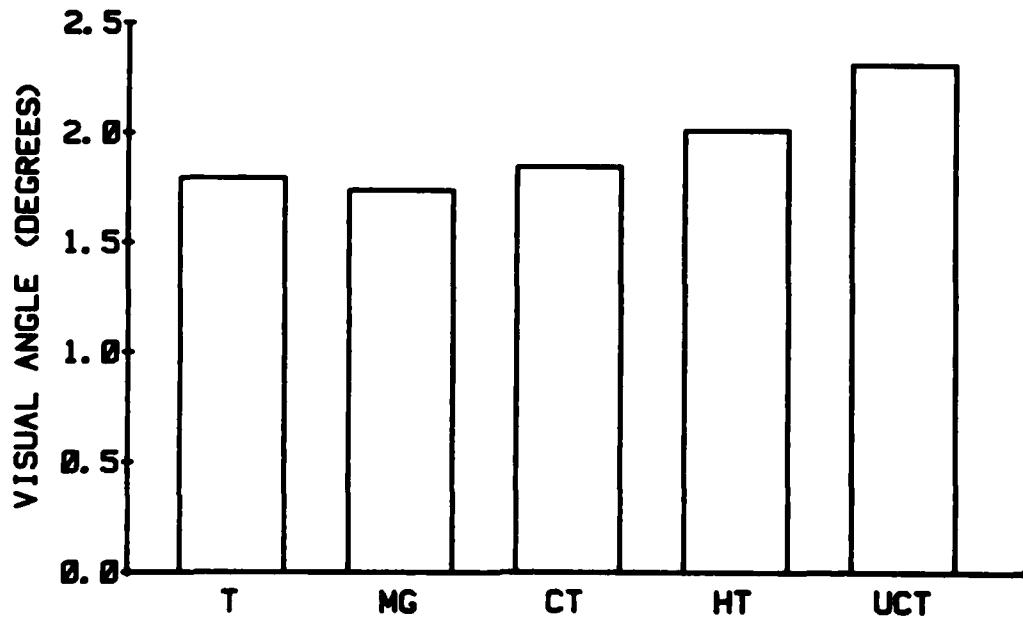


Figure 10. Subjects' Performance for Each Target While Viewing a Green TV Display at a 40:20 Contrast Ratio

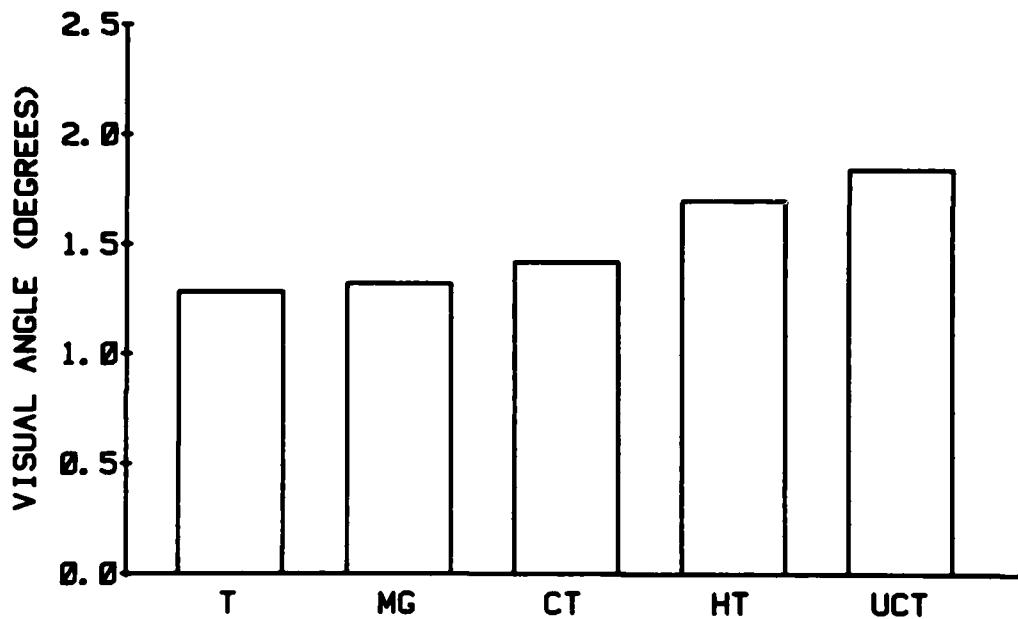


Figure 11. Subjects' Performance for Each Target While Viewing a Red TV Display at a 40:1 Contrast Ratio

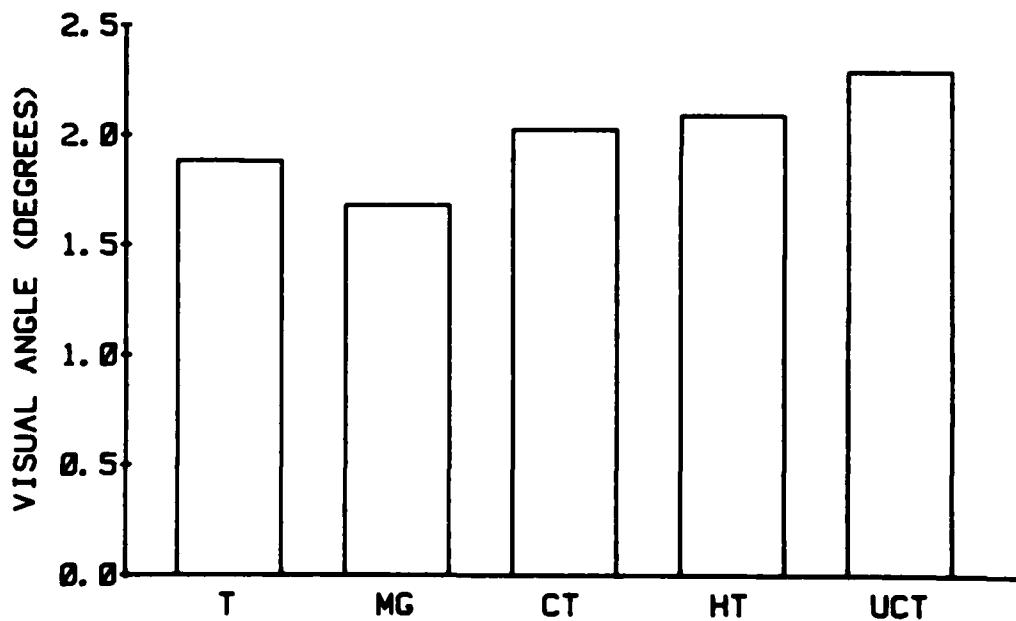


Figure 12. Subjects' Performance for Each Target While Viewing a Red TV Display at a 40:20 Contrast Ratio

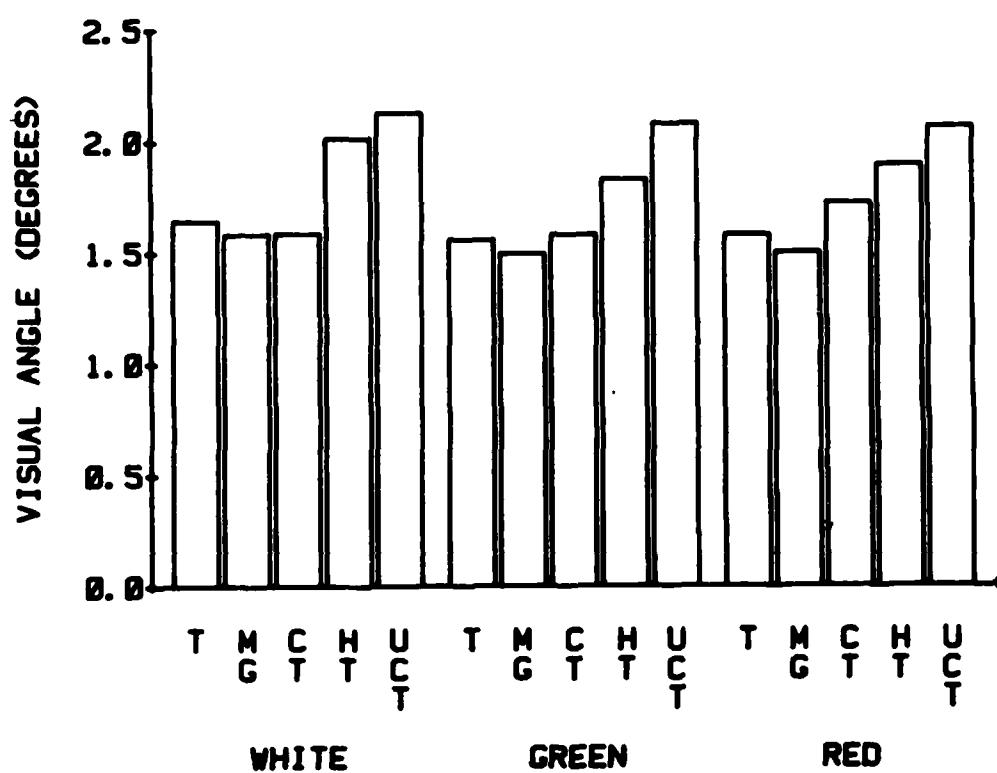


Figure 13. Subjects' Performance for Color and Targets  
Collapsed Across Contrast

## DISCUSSION

No significant differences in target recognition performance due to color were found. However, there is an alternative method of evaluating performance. Since this study partially simulated an airplane diving on a ground target, the simulated distance, or slant range (SR), from the sensor (TV camera) to the target at the moment of recognition can be calculated using the mean visual angle from the various experimental conditions. (See Appendix B for a complete explanation of the simulation's parameters and of the SR calculation.) These SR calculations allowed the evaluation of the subject's performance in terms of a field situation. Table 5 shows the SRs for select experimental conditions. SRs varied less than 6.5 percent in relation to color within either the high or low contrast conditions. Thus, based on this study, the impact of TV display color with respect to SRs that might be encountered in the field is negligible.

The nonsignificant color result can be related to previous studies. Campbell and Robson (1968) and VanNes and Bouman (1967) measured contrast threshold functions (CTFs) of subjects using white, green, and red sine-wave gratings as stimuli. They showed no significant differences among CTFs due to color. According to Fourier

TABLE 5. SLANT RANGES (SR) FOR SELECT EXPERIMENTAL CONDITIONS

Contrast Ratio	Color	Mean Visual Angle (deg)	SR (ft)
40:1	White	1.580	2853
	Green	1.482	3042
	Red	1.513	2980
	All	1.525	2956
40:20	White	1.999	2255
	Green	1.939	2325
	Red	1.996	2259
	All	1.978	2279

theory, any complex target stimulus can be resolved into its constituent sine-wave components. Thus, if the sine wave thresholds show no color differences, then one might expect a similar result for a superposition of sine waves such as a complex target. Figure 14 shows the spatial frequency information characteristics of the video system and the stimulus in relation to the viewer. Curve A represents the total bandpass characteristics of the video system for the high contrast condition. Curve B shows a reciprocal CTF. Since there were no significant differences in CTFs due to color, only one curve is shown. Curves C, D, and E represent the Fourier transforms of a target as it is zoomed from relatively small to successively larger sizes, respectively. At the onset of a stimulus presentation (Curve C), the video system attenuated the higher spatial frequencies of the target (represented by the dot) and the subject could not recognize the target. As the target size increased (Curve D), the higher spatial frequencies moved closer (lower) toward the bandpass capability of the display system but still could not be seen by the subject due to his CTF.

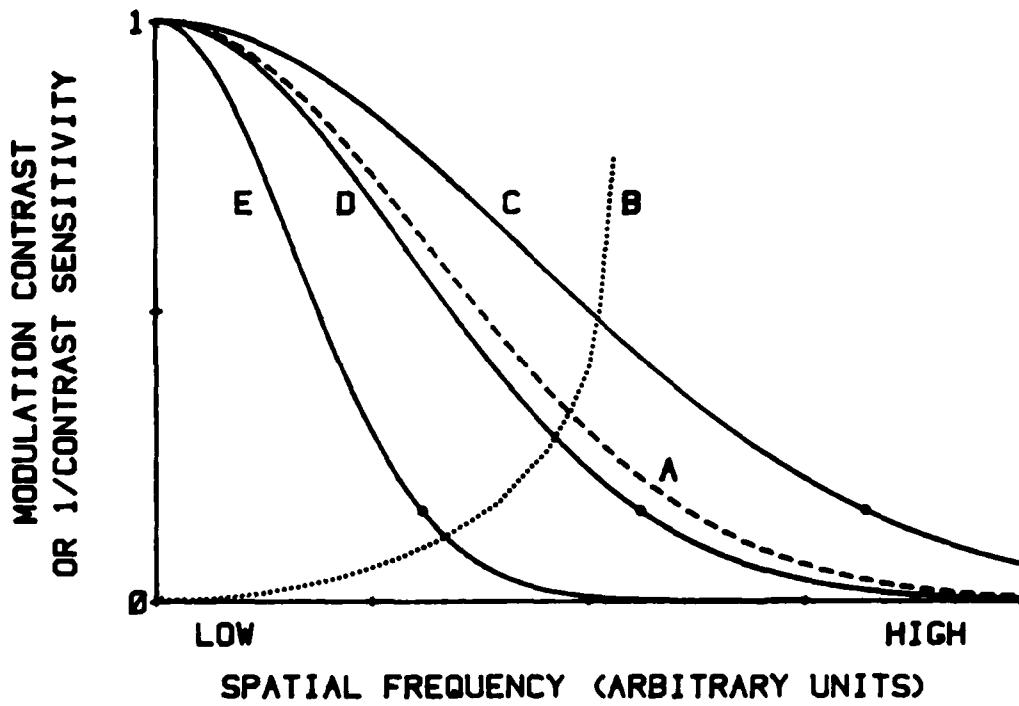


Figure 14. Bandpass Characteristics of the Video System (A), the Reciprocal of the Contrast Threshold Function (B), and the Fourier Transforms of a Target Zoomed from Small to Large (C, D, E, Respectively)

Curve B represents the subjects' CTF, i.e., the minimum contrast at a given spatial frequency, required by the subject for detection of a sine wave. The target could be identified only after both the higher spatial frequencies of the target were passed by the video system and the minimum contrasts required by the subject were met or surpassed (Curve E). If the CTFs (Curve B) had varied more as a function of color, the subject would have acquired the higher spatial frequency information either earlier or later, thus possibly causing significant variations in target recognition. However, as previous studies have

shown, the CTFs have no significant variation due to color, thus the subjects would be expected to acquire the information at approximately the same size for a given target, causing the nonsignificant color effect.

There is no reasonable physical hypothesis to explain the significant color by target interaction. Since this only accounted for less than 1 percent of the total variance, it can probably be viewed as an artifact and not a real effect within the context of this study.

The effect of display contrast on target recognition performance was highly significant, thereby replicating the findings of several previous studies (Task, 1979; Bruns et al., 1972; Erickson and Hemingway, 1970). Simulated SRs for high and low contrast displays were 2956 feet and 2279 feet, respectively (see Table 5). The 677 feet difference represents a 23 percent decrease in SR required to recognize a target when using a low contrast instead of a high contrast TV display.

Subjective comments from some operators in the field had suggested that targets under low contrast conditions (e.g., cloud shadows on a ground target) were more difficult to recognize when viewing a green display than a white display. However, no significant color or color by contrast effects were found, indicating that the difficulty in recognizing the shadowed target may have been due instead to sensor limitations. Apparently, the automatic gain control of the sensor adjusted to the higher average scene radiance and, therefore, compressed the dynamic range of the shadowed target area. Within the context of this study, the nonsignificant color and color by contrast

effects seem to indicate that the current practice using various display colors for different tactical situations probably should not affect an operator's overall target recognition performance, even under low TV contrast conditions.

An examination of the target's confusion matrix, in Table 6, revealed several notable features. First, the majority of errors were made while trying to recognize the UCT. It was confused 19 times with the CT and 13 times with HT. Second, the confusion matrix was asymmetrical. Even though the UCT was often confused with the CT, the CT was never confused with the UCT. It can be hypothesized that the subject waited until there was sufficient information present before he was confident enough to make an accurate recognition. Based on this assumption, the asymmetry might be explained by a missing information hypothesis. Suppose the CT contained certain information that the UCT did not, which allowed the CT to be unambiguously recognized. However, since the UCT may have lacked certain unambiguous information, two responses could have been possible. The subject might have guessed before acquiring adequate information, thereby causing a high error rate as shown in Table 6, or he could have conservatively waited until the target was of sufficient size so that if the required information had been present, it would have then been visible. If the subject did, indeed, wait until he was confident that sufficient information would have been displayed had it been the CT, then the mean correct target recognition angle for the UCT would have been larger than the CT. Data from Table 3 and Figures 7 through 13 show the UCT to be consistently recognized at the largest recorded visual

angles. The asymmetry of the confusion matrix lends some support for the missing information hypothesis whereby target recognition is largely affected by subjects' strategies.

TABLE 6. NUMBER OF TIMES THE PRESENTED TARGET WAS CONFUSED WITH ANOTHER TARGET

Response	Target Displayed				
	T	MG	CT	HT	UCT
T	-	7	0	2	2
MG	1	-	0	5	4
CT	0	0	-	0	19
HT	0	0	0	-	13
UCT	0	4	0	0	-

## APPENDIX A

### List of Equipment from Figure 2 Diagram

Athena 4000TSM 16mm motion picture projector  
Cohu 2810 TV camera  
Cohu video distribution amplifiers  
Tektronix 632 TV, 525 line rate (subject)  
Tektronix 7613 oscilloscope  
Tektronix C-50 oscilloscope camera  
Hewlett-Packard 6946A TV (experimenter)  
Systems Research Laboratory custom made digitizer, video blanking,  
video switching  
CVI 615 video test generator

## APPENDIX B

### Angle/Time Function Derivation and Slant Range Calculation

The following figures and equations show the derivation of the geometrical relationship between a target's angular size on a TV with respect to the observer and an airplane's closure time at a given velocity (hereafter referred to as the angle/time function; ATF), for an electro-optical target acquisition system.

Figures 15 and 16 depict the observer/TV display and sensor/target geometry of the ATF, respectively. Figure 17 illustrates equation (9).

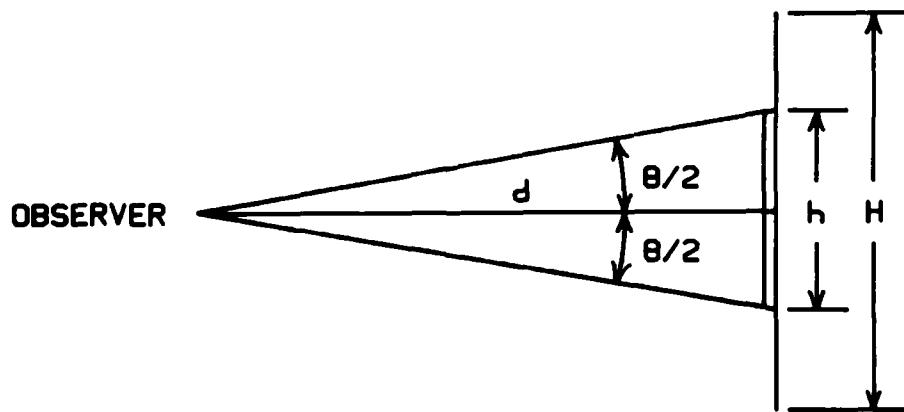


Figure 15. Observer/TV Display Viewing Geometry

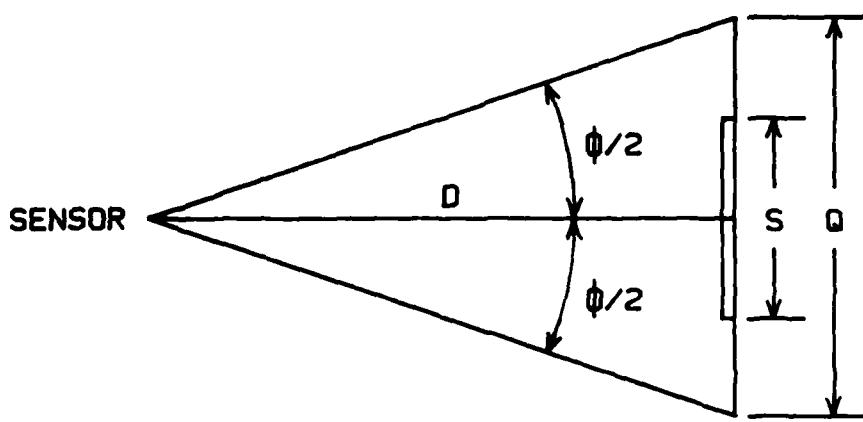


Figure 16. Sensor/Target Optical Geometry

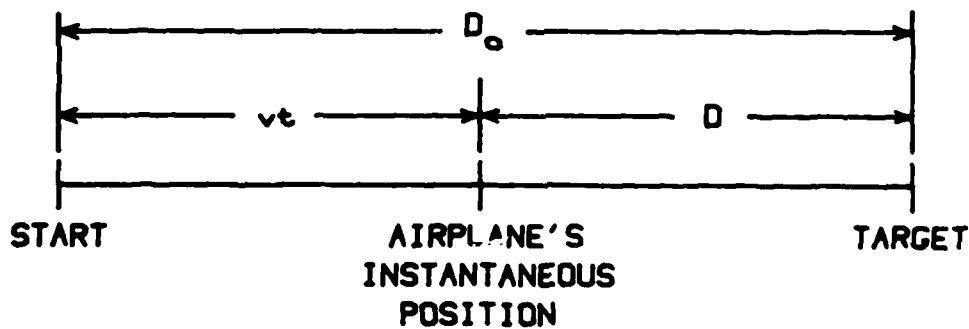


Figure 17. Schematic Representation of Equation (9)

$d$  = observer/TV viewing distance (inches)

$D$  = distance (in feet) to the target after having traveled for a given time (in seconds) at a given velocity (in feet/second)

$D_0$  = starting distance from sensor to target (feet)

$h$  = height of target on TV (inches)

$H$  = height of TV raster (inches)

$\phi$  = sensor field of view (FOV; degrees)

$Q$  = size of sensor field in the plane of the target (feet)

$S$  = actual size of target (feet)

$t$  = airplane's closing time (in seconds)

$\theta$  = angular size of target on TV (degrees) as a function of  $t$

$v$  = airplane's closing velocity (feet/second)

From Figure 15, the angular size of the target on the TV is:

$$\theta = 2 \arctan \left( \frac{h}{2d} \right) \quad (2)$$

The 1:1 mapping of the image from sensor to TV is expressed as:

$$\frac{h}{H} = \frac{S}{Q} \quad (3)$$

Solving for  $h$ :

$$h = H \left( \frac{S}{Q} \right) \quad (4)$$

From Figure 16, the angular size of the sensor field of view is:

$$\tan \frac{\phi}{2} = \frac{Q}{2D} \quad (5)$$

Solving for  $Q$ :

$$Q = 2D \left( \tan \frac{\phi}{2} \right) \quad (6)$$

Substituting (6) into (4):

$$h = H \left[ \frac{S}{2D \left( \tan \frac{\phi}{2} \right)} \right] \quad (7)$$

Substituting (7) into (2):

$$\theta = 2 \arctan \left\{ \frac{H \left[ \frac{S}{2D \left( \tan \frac{\phi}{2} \right)} \right]}{2d} \right\} \quad (8)$$

D, from Equation (8), must be expressed as a function of t. From Figure 17:

$$D = (D_0 - vt) \quad (9)$$

Substituting (9) into (8) and simplifying to obtain  $\theta$ :

$$\theta = 2 \arctan \left[ \frac{HS}{4d(D_0 - vt) \left( \tan \frac{\phi}{2} \right)} \right] \quad (10)$$

Equation (10) is the ATF (see solid line in Figure 18). The values of the parameters for equation (10) described below were chosen to represent a modern fighter diving on a ground target. The airplane dove for 17 seconds (t) at 575 feet per second (v) towards a 25-foot target (S), that was at the onset, 11,275 feet away ( $D_0$ ). The target was viewed via a sensor (TV camera) having a 2.6-degree FOV ( $\phi$ ). The operator viewed a 4-inch square TV (H) at 28 inches (d). It must be noted that essentially an infinite number of parameter values could be chosen for the ATF. The values here were selected to both represent an airplane and to fit the angular size changes of the stimuli as they appeared to the subject in this study (see dashed line in Figure 18).

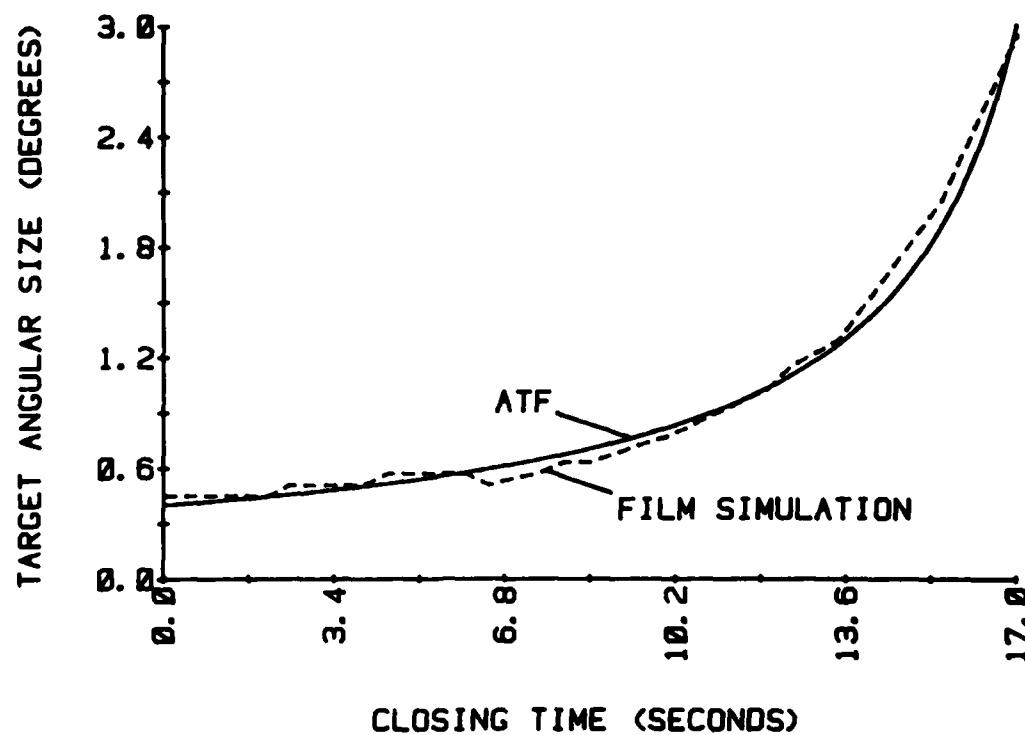


Figure 18. The Target's Angular Size in Degrees with Respect to Closing Time, for Both the Angle Time Function (Solid Line; Equation 10) and the Study's Film Simulation (Dashed Line)

The ATF can be used to describe the study's stimuli with respect to a field situation. In terms of that simulation, the ATF can also be used to calculate the slant range (SR; distance from airplane to target in feet) to the target, given the angular size of the target at recognition (in degrees) from any experimental condition of interest in the study. The SR calculation is best illustrated through use of an example. First, Equation (10) is solved for  $t$ , as shown in Equation (11). The mean angular size of the target at recognition for the high contrast condition was 1.525 degrees. Solving Equation (11),

$$t = \frac{D_0 - \left[ \frac{HS}{\left( \tan \frac{\theta}{2} \right) 4d \left( \tan \frac{\phi}{2} \right)} \right]}{v} \quad (11)$$

$t = 14.467$  seconds. Since  $D$  is actually SR, Equation (9) is used to calculate SR. Thus, for this field situation using a high contrast TV, the target was recognized at about 2956 feet away.

$$\begin{aligned} SR &= (D_0 - vt) \\ &= (11,275 \text{ feet} - (575 \text{ feet/second}) (14.467 \text{ seconds})) \\ SR &= 2956 \text{ feet} \end{aligned} \quad (12)$$

Table 5 shows the various SRs for select experimental conditions.

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